RADIATION TEST REPORT for

Tri-axial Sensor Head – Ethernet Standalone

ENGINEERING DIRECTORATE

AVIONICS SYSTEMS DIVISION

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**National Aeronautics and
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1.0 INTRODUCTION

Candidate elements of the Tri-axial Sensor Head – Ethernet Standalone for the International Space Station (ISS) were tested at the Indiana University Cyclotron Facility (IUCF) to assess susceptibility of the unit to high-energy ionizing radiation.

The test was conducted on 27, 28 January, 2003 and the summary results are presented in this report.

The members of the test team were:

Pat O'Neill, NASA/JSC, Radiation Environments Manager – Test Conductor

Kyson Nguyen, Test Engineer, Lockheed-Martin

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William Foster, Glenn Research Center, Project Manager

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Dr. Ken Murray, IUCF, Senior Radiation Effects and Dosimetry Consultant

2.0 TEST OBJECTIVES

The objectives of the radiation testing were to obtain data to make preliminary estimates of ionizing radiation induced functional interrupt rates and other error rates that can be expected on orbit.

3.0 BACKGROUND

A definition of the test philosophy and the radiation environment model used is presented in this section.

3.1 Radiation Test Philosophy Hardware elements must be able to operate in the environment for the duration of their missions. The two major elements of the ionizing radiation environment are the deposition of energy from Total Ionizing Dose (TID) and the Single Event Effects (SEE) produced by high energy particles like protons and atomically heavier ions. The TID experienced by any hardware element is a function of its location on the vehicle. Shielding values are available for various locations within the spacecraft. The SEE's experienced on orbit are not substantially mitigated by shielding because of the high energy of the particles producing the effects.

Radiation testing for SEE's with high energy protons is designed to establish the susceptibility of a given test article to trapped protons in the South Atlantic Anomaly (SAA) and heavy ions due to Galactic and Solar Cosmic Rays. A SEE can be detected as:

- **Single Event Upset (SEU)** – an event like a bit flip resulting in a data error only.
- **Functional Interrupt (FI)** – an event requiring a software reboot or a power cycle.
- **Single Event Latchup (SEL)** – an event where the device has an abnormal conduction path established by the ionizing radiation and as indicated by a primary power supply current change. Power must be recycled to regain control and/or to save the device from destruction.
- **Single Event Burnout (SEB)** – an event where the device has an abnormal conduction path established by the ionizing radiation and is destroyed almost immediately.

The occurrence of a SEE is a single sample observed from a random process. The more samples (in this case SEE's detected) observed, the better the estimate of the Mean Time Between Failures (MTBF) for that specific type of SEE. The goals of this testing are to establish estimates of the MTBF's for each type of SEE detected for a given test article or electronic component.

The probability of an SEE occurring within a test article is related to the number of particles per square centimeter (called fluence) allowed to impinge on the device. The general criterion used in testing with protons is to expose each beam position or test article to a fluence of 10 billion (1E10) protons/cm2.

Even though the SEE susceptibilities measured during testing were only from proton testing, the MTBF's cited in this report are the composite MTBF's due to the nominal proton (primarily SAA trapped protons) and the nominal heavy ion (Galactic Cosmic Rays) environments. The procedures for deriving the MTBF's were determined using the software tool PRODUCT [10]. The proton SEE MTBF's from proton test results were determined using the Bendel A method and are described in [6]. The heavy ion SEE MTBF from proton test results was calculated as described in [5] and [7], using the formula:

MTBF = 6 years/Number of SEE's in 1E10 protons/cm2

3.2 Radiation Environment Definition For typical orbits for the space shuttle or the space station considered here (51.6 - 57 degree inclination, 270 nmi altitude), the nominal ionizing radiation environment consists of Galactic Cosmic Rays and trapped protons and electrons. The Galactic Cosmic Ray flux was modeled with a solar modulation algorithm [1], [2] whose accuracy has been demonstrated over four solar cycles. The trapped proton and electron radiation spectrum was generated using the AP8 model with solar minimum conditions (1964 epoch, 1965 International Geomagnetic Reference Field (IGRF)) [3]. Orbit average environments were

determined for solar minimum conditions with 0.1" thick spherical aluminum shielding for quiet conditions and no earth shadow. Transport and geomagnetic shielding models can be found in [4]. The trapped electron spectrum was only used for TID calculations. These environments are consistent with those defined in [8] and [9].

4.0 GENERAL DISCUSSION

All testing was done with a proton beam energy of 190 Million-electron Volts (MeV). The normal beam diameter of approximately 6 cm was passed through various copper vignettes to adjust the size of the final beam allowed to radiate the test article. The beam positions and required vignettes were pre-planned and documented (see Appendix A) in the expected order of execution.

4.1 Test Hardware

The elements of the Triaxial Sensor Head – Ethernet Standalone system tested are identified in the Appendix.

5.0 SUMMARY OF TESTING

This section discusses the results of testing each element. Included in the discussion are the MTBF's noted for the elements that reacted to the beam. The MTBF's reported are the errors expected from both protons and heavy ions.
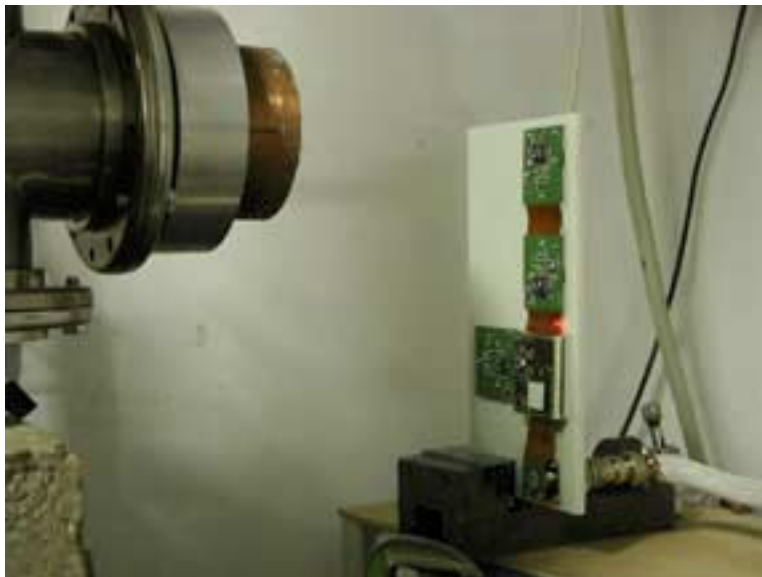
Figure 1 TSH-ES setup in the test configuration

The TSH – ES is for measuring vibration (acceleration) on spacecraft such as ISS. During this test, the TSH – ES is receiving a constant voltage from the accelerometer (not present) to simulate a constant acceleration of 1.1 g. This is a calibrated voltage source.

Position 1 X-axis A to D and Op Amp had one error (30 mA current increase (15%) and device changed modes to try to read actual acceleration rather than the calibration mode). This was a hard failure of the x-axis and the voltage leads had to be clipped in order to proceed with testing the other channels.
1 failure occurred in 1.25E9 protons/cm**2.
Hard Failure, On-orbit MTBF for position = 223 days

Position 3 Z-axis A to D and Op Amp had one error (30 mA current increase (15%) and device changed modes to try to read actual acceleration rather than the calibration mode). This was a hard failure of the x-axis and the voltage leads had to be clipped in order to proceed with testing the other channels. **Note: the beam flux was reduced 5x for this run to be absolutely sure that this failure mode is dose rate independent.**
1 failure occurred in 2.65E9 protons/cm**2.
Hard Failure, On-orbit MTBF for position = 473 days

Positions 5 Y-axis A to D and Op Amp – Not exposed.

Positions 4Z-axis High precision reference voltage - No errors.

Positions 2 and 6 X and Y-axis High precision reference voltage – Not exposed.

Position 7a CPU & more had one error (15% current increase and device changed modes to try to read actual acceleration rather than the calibration mode) just like position 1 and 3. This time the op amp in position 5 was failed (y-axis) and the voltage leads had to be clipped in order to proceed with testing. It is not clear why position 5 failed since it was not being exposed on this run.
1 failure occurred in 1.0E10 protons/cm**2.
Hard Failure, On-orbit MTBF for position = 1790 days

Position 7b CPU & more had one error – lost either net, power cycle required.
1 failure occurred in 1.0E10 protons/cm**2.
Functional Interrupt, On-orbit MTBF for position = 1790 days

Position 8a Flash memory and SDRAM had 4 errors – segment fault detected in RAM.
4 failures occurred in 1.31E10 protons/cm**2.
Functional Interrupt , On-orbit MTBF for position = 586 days

Position 8b Flash memory and SDRAM had 1 error – lost either net socket connection – system hung-up
1 failure occurred in 1.31E10 protons/cm**2.
Functional Interrupt , On-orbit MTBF for position =   2350 days

6.0 CONCLUSIONS

Each position of all units tested received a minimum fluence of 1E10 protons/cm2 which is equivalent to a TID of 600 Rads(Si). No degradation in performance due to the TID was noted.

The TSH-ES experienced hard failures and functional interruptions which generally require power cycle to recover.

The individual error MTBF's presented above are combined here to in order to get a better feel for the overall performance. We have separated the errors according to the type of error.

1.) Error type = Hard failure, Position 1, 3, 7a combined
On-orbit MTBF = 140 days

 2.) Error type = Functional Interrupt, Position 7b, 8a, and 8b combined
On-orbit MTBF = 372 days

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9. NSTS 07700, Volume X, Book 1 and Book 2.

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APPENDIX A PARTS LIST AND BEAM POSITION

	AD1556AS	24 – Bit AD Converter	Analog devices		17U	1		1" x 1.5"
	AD1555AP	24 – Bit AD Converter	Analog Devices		16U	1		1" x 1.5"
	AD8571AR	Op Amp	Analog Devices		15U	1		1" x 1.5"
	AD780AR	High Precision Reference	Analog Devices		18U	2		1" x 1.5"
	AD1556AS	24 – Bit AD Converter	Analog devices		11U	3		1" x 1.5"
	AD1555AP	24 – Bit AD Converter	Analog Devices		10U	3		1" x 1.5"
	AD8571AR	Op Amp	Analog Devices		8U	3		1" x 1.5"
	AD780AR	High Precision Reference	Analog Devices		12U	4		1" x 1.5"
	AD1556AS	24 – Bit AD Converter	Analog devices		5U	5		1" x 1.5"
	AD1555AP	24 – Bit AD Converter	Analog Devices		4U	5		1" x 1.5"
	AD8571AR	Op Amp	Analog Devices		2U	5		1" x 1.5"
	AD780AR	High Precision Reference	Analog Devices		6U	6		1" x 1.5"
TQM8XXX	XPC850SRZT50B	CPU	Motorola		A	7		1" x 1.5"
TQM8XXX	MAX3222CAP	RS-232 Driver	Maxim		B	7		1" x 1.5"
	LXT905LE	Universal Transceiver	Intel		24U	7		1" x 1.5"
	PDIUSBP11AD	Univ. Serial Bus Transceiver	Philips		22U	7		1" x 1.5"
	SI9430DY	P-Channel Mosfet	Vishay		20U	7		1" x 1.5"
	MC79L05ACD	Voltage Regulator	TI		21U	7		1" x 1.5"
	T-14068	Isolation Transformer	Rhombus		23U	7		1" x 1.5"
	PM-2DD20MHZ	Crystal	M-Tron		4X	7		1" x 1.5"

TQM8XXX	L160DB90VC	Flash Memory	AMD		C	8		1" x 1.5"
TQM8XXX	HY57V651620B	SDRAM	Hyundai		D	8		1" x 1.5"